No: 9/91 **Ref: EW/A344** **Category: 1a**

Aircraft Type and Registration:	Concorde 102, G-BOAE
No & Type of Engines:	4 Rolls-Royce Olympus 593/610 turbojet engines
Year of Manufacture:	1977
Date & Time (UTC):	4 January 1991 at 1207 hrs
Location:	Over North Atlantic, estimated approximately 27° W
Type of Flight:	Public Transport
Persons on Board:	Crew - 9 Passengers - 49
Injuries:	Crew - None Passengers - None
Nature of Damage:	Portion of lower rudder lost, superficial damage to tailcone
Commander's Licence:	Airline Transport Pilot's Licence
Commander's Age:	53 years
Commander's Flying Experience:	14,773 (of which 5,251 were on type)
Information Source:	AAIB engineering investigation

History of Flight

The aircraft departed Heathrow at 1055 hrs on a scheduled service to J F Kennedy Airport, New York. At 1207 hrs at Mach 2 and flight level 560 the crew felt what they thought was an engine surge. The effect was of very brief duration (0.5 to 1.0 secs) and all engine parameters appeared normal. The event marker, which signals the Flight Data Recorder (FDR), was manually operated by the flight crew. During descent and deceleration at 1403 hrs, Mach 1.1 and flight level 410 more unusual vibration was felt. It lasted for about 10 seconds and again the event marker was pressed. Subsequent examination of the FDR traces showed no anomalies in any engine or other parameters at or near the event marks. The flight continued normally but on landing at New York it was found that a portion of the lower rudder was missing together with most of the skin on the right side above the Powered Flying Control Unit (PFCU) attachment structure. There was also some indentation, scoring and paint smearing on the tailcone almost immediately below the rudder, and some damage near the bottom aft corner of the lower rudder where it had been holed. The lower rudder was removed from the aircraft and returned to the UK for examination.

Initial Examination

The Concorde aircraft has two independent rudders, an upper and a lower, each operated by a dual acting PFCU. Each rudder is of aluminium skinned honeycomb construction and is composed of two structurally separate "pockets", one above the re-inforced attachment rib for the PFCU and one below. The failure in G-BOAE occurred in the top pocket of the lower rudder (see Photograph); a triangular area was lost from the aft end of the pocket bounded by almost all the trailing edge, the rearmost 23" of the top closure rib and, on the left skin, a ragged diagonal tear which showed signs of bending reversals in its failure. Also, most of the skin on the right side was lost forward to about seven inches aft of the leading edge spar.

The peripheral evidence on the rudder and tailcone was studied and at first it appeared unlikely that at a supersonic flight condition a detaching piece of rudder skin could descend almost vertically and hit the tailcone, but consideration of the evidence assisted by a study by British Aerospace of the dynamics of the panel's detachment indicated that, at whatever flight condition, that is what had happened. Consideration was given to whether the detachment had occurred at either take-off or landing when it was suggested that airflow over the fin and rudder might have been influenced by the wing vortices and been less directly rearwards. Aerodynamic advice was that even at low speed fin/rudder airflow is essentially chordwise and enquiries at Heathrow and New York, including examination of the radar recordings, found no evidence of pieces detaching from the aircraft in those phases of flight.

It was unclear as to whether the lost rudder structure and skin had detached in one or more pieces but it did appear, and was later confirmed from metallurgical examination, that the major piece of skin on the right side, with or without the trailing edge triangle of rudder, had detached in one piece with a progressive clockwise failure around its periphery. The failure of its attachment to the flange of the top closure rib started at the aft end and progressed forwards. The skin then tore downwards towards its bottom edge, this fracture line being unaffected by a bonded doubler at the top hinge location, and hinged about a line parallel to the bottom edge at a change of thickness. It finally tore along this line and pivoted, leading edge downwards, about some remaining attachment at the aft end, leaving some circular arc scoring on the adjacent skin as it did so.

The most likely interpretation of the other peripheral evidence is that as the skin panel swung downwards one corner penetrated the lower rudder near its bottom aft corner, causing the panel to pivot again about that point and slam onto the tailcone. There were edge markings on the tailcone and some scoring evidently made by rivets of the same pitch as those along the top edge of the skin panel. It was also apparent that the panel had been pressed down onto the tailcone leaving extensive smearing of blue paint on the white tailcone and local inward deformation of the tailcone skin, indicative of high distributed loading between the two. The blue smears on the tailcone were identified chemically with the blue paint on the rudder.

History of Upper and Lower Rudders, Serial No VW25

The subject lower rudder carried the same serial number as the upper rudder which failed on Concorde G-BOAF on 12 April 1989 (AAIB Report 6/89) over the Tasman Sea and was also on that aircraft at that time as they both had been since new. The rudders had been manufactured as a pair.

In May 1980 both rudders were modified with an extension to the blunt trailing edge which increased the fineness ratio of the fin/rudder combination and was part of a performance enhancement package. The V-sectioned extension was bonded and riveted in place and filled with a resin filler. The design and execution of this modification were implicated in the failure of upper rudder VW25 in that corrosion had developed between the honeycomb core and the skin where defective sealing of the rivets appeared to have allowed a path for moisture ingress. As part of the follow-up action following the failure on G-BOAF British Airways introduced a repair scheme (55-42180) to rectify these sealing deficiencies; new fasteners were introduced which provided better sealing and a single layer of glass fibre reinforced resin was laid in a strip over the heads of the fasteners. This scheme was applied to VW25(lower) when it was removed from G-BOAF in July 1990 and before it was fitted to G-BOAE.

Following the accident to G-BOAF on 12 April 1989 British Aerospace issued a Campaign Wire, SST-CW-007 also dated 12 April, which required a visual check of rudder surfaces and a tap test for defective bonding of the entire rudder surfaces. This requirement was implemented by British Airways through a Special Check (CONC 55/1216/X) which was carried out on G-BOAF on 14 April.

The visual and tap checks were incorporated into the 'S2' check in the Aircraft Maintenance Schedule (AMS) at the end of June 1989, the tap test now being restricted to the rear 6 inches of each rudder. The subsequent maintenance history, as relevant to lower rudder VW 25 first on aircraft G-BOAF and then on aircraft G-BOAE, is listed below. The S2 check occurs at 460 hour intervals and the Intercheck at 1100 hour intervals.

14 Apr 1989 at 8352 hours on G-BOAF	Special Check
11 Oct 1989 at 8891 hours on G-BOAF	S2 Check
25 Feb 1990 at 9221 hours on G-BOAF	S2 Check
17 Jul 1990 at 9650 hours on G-BOAF	Intercheck - VW 25(lower) removed from BOAF
28 Aug 1990 at 14365 hours on G-BOAE	Intercheck - VW25(lower) installed in BOAE
4 Jan 1991 at 14714 hours on G-BOAE	Rudder failure

The lower rudder VW25 was not subjected to a tap test between the time it was installed on G-BOAE and its failure on 4 January nor was it required to be.

In June 1989, together with the visual checks and tap tests, British Airways, in consultation with British Aerospace, introduced an Acoustic Flaw Detection (AFD) technique into the maintenance schedule at the Intercheck. On 14 May 1990 the Alert Service Bulletin (ASB) 55-A-007 was issued by British Aerospace. This contained the Manufacturer's specification of appropriate tap testing and AFD. This bulletin had already been made mandatory by the CAA in AD 022-04-89 in April 1989 in anticipation of its issue and British Airways were already in compliance with the periodicity of the prescribed tests. The bulletin required the AFD to be carried out initially at or before 255 flying hours or 3 months, whichever the sooner, from receipt of the bulletin. Under the terms of the amended AMS and the ASB the Acoustic Flaw Detection was not applicable to G-BOAF before the lower rudder was removed on 17 July 1990 at an Intercheck, at which time the lower rudder was designated for removal for rectification of wear in its hinges. A work card for the AFD inspection was raised but was certified for the lower rudder as, "N/A being changed" i.e.not applicable. This particular AFD inspection was not a routine feature of workshop rectification of the rudders and was not called up for VW25 while it was in the workshop.

Lower rudder VW25 was installed on G-BOAE on 28 August 1990 at an Intercheck on that aircraft. A work card had been raised for the AFD on G-BOAE's rudders but, as before, the work card for the lower rudder was annotated, "N/A- Replacement serviceable unit fitted" and was certified with a British Airways Inspector's stamp. At the time of the rudder's failure on 4 January 1991 G-BOAE had flown a further 349 hours and therefore no further Intercheck or AFD had been carried out.

In summary, over the period following the failure of upper rudder VW25, the lower rudder was inspected on 3 occasions visually and by the tap test method, the last of which was 778 operating hours and over 10 months before its failure, and it had not been inspected at any time by AFD.

Detailed Examination

The examination of the fractures in the rudder's metal skin and edge fittings at RAE Farnborough showed that there had been no pre-existing failure in the recovered portions of those components. Their failure had been in overload but some of the fracture surfaces, those in the top edge and trailing edge closure channel sections, had suffered fretting or hammering damage. The diagonal tear in the left skin had suffered a number of reversals consistent with the missing portion fluttering as it detached.

The separation of the right skin from the peripheral metallic parts of the pocket began at the rear of the top closure rib. The distortion suffered by the rib's right flange and its rivet holes showed that at the aft end the skin had been locally free from the honeycomb and had lifted flatwise off the surface, remaining almost parallel with it. The skin had thus disbonded from the honeycomb before the metallic failures occurred. Further forward the skin's detachment from the top closure rib became a progressive tearing process as previously described.

The adhesives section of the Royal Aerospace Establishment (RAE) Materials and Structures Department at Farnborough conducted a close examination of all the bonding surfaces exposed on the failed pocket. No clear evidence of any bonding defect or corrosion which could be associated with the failure and break-up of the pocket could be found. The bonding faces of the doubler at the hinge position showed signs of having sustained overload in failing but as the presence of the doubler had not influenced the direction of the tear in the outer skin it would appear again that the bonding rupture had preceded the skin failure. Along the diagonal tear in the left skin four small areas were seen where there had been separation of the adhesive from the skin's inner surface. It was conjectured that this may have been caused by water penetration with consequent ice formation which would form a wedge and progressively lift the adhesive from the skin. Such disbonding has been seen to precede the development of corrosion on the aluminium surface thus exposed. These small indications may, therefore, show the furthest forward extent of any area or areas of disbonding that had progressed from water ingress along the trailing edge.

In addition to showing evidence of having sustained overload in failing the adhesive surfaces gave indications that the bonding failures, like the metal skin failures, had progressed from the rear forwards. Any evidence of the nature of the initial defect had, therefore, most probably been lost with the detatched material.

Some small areas of corrosion or defective bonding were found but they were obviously not involved in the initiation of the pocket's failure or its development. These areas were found between the skin and the flange of the top closure rib (one area, 0.2mm wide by 4mm) and at the pocket's forward edge where joints in the members attaching to the skin required the adhesive to act as a filler in small gaps (three areas, penetration generally 50mm maximum width 25mm).

The top closure rib had been partially filled with low density epoxy filler and in some places the bonding between the filler and the rib flanges had been lost. Where this had happened the aluminium surfaces were stained suggesting that the condition had existed for some time and had not just been the result of overloads during the pocket break-up. This disbonding, coupled perhaps with substantial associated corrosion, could have reduced the stiffness of the top rib near the trailing edge with possible consequences for its resistance to fatigue.

During the detailed examination of the honeycomb/adhesive failures it was realised, because of some colour difference, that the adhesive used was not AF-130 (brown coloration, when cured, and used with a clear or yellow primer) which is a modified epoxy manufactured by 3M but was in fact Redux 322 (grey-green coloration and used with a red primer). Later chemical analyses by BAe confirmed this but it had also been noted that Redux 322 contains an aluminium filler whereas AF130 does not and at places on the exposed adhesive surfaces segregation of the grey filler, giving a banded effect, could be seen.

The process drawing for the manufacture of the rudders specified AF130 by name though the Concorde Design Handbook stated that, "The supplier's name and reference shall not be used to identify materials on drawings". A search of the archives failed to unearth any document modifying that drawing requirement or authorising a particular concession for VW25. However, the list of approved non-metallic materials (Note Technique D.04.3006), referenced by the Concorde Design Handbook, showed both AF130 and Redux 322 with their respective primers as complying with Concorde Materials Specification CM37, though the list named only AF130 under that specification as the "product used by BAC" for applications involving large surfaces (such as the rudders) and high operating temperatures.

In view of the possible role of paint stripping operations in promoting access of moisture to the rudder interior and exacerbating its effect (AAIB Report 6/89, Sect. 1.16.3) tests were carried out by RAE Farnborough to compare the effects of stripper on AF130 and Redux 322. The stripper was of the type which had been used by the operator on VW25.

In contrast to the negligible effect of stripper on AF 130 it was found that Redux 322 was badly affected. A sheet of the cured adhesive immersed in stripper was swollen and disintegrating in two hours. A more realistic trial with a thin layer of stripper held in contact with adhesive bonded to aluminium sheet for a longer period caused the adhesive to discolour, crack and soften. Thus if small amounts of stripper had entered via unfilled hollow rivets in the period May 1980 to July 1990 it could have caused local weakening of the Redux 322 and facilitated attack by water. If water-induced disbonding was already present when stripper was used then the stripper could have spread some distance from the ingress locations.

It was decided, early in the investigation that the remaining bonded skin and honeycomb on the damaged pocket from VW25 presented an opportunity to test the bond strength of aged material which had been subjected to normal service use and the appropriate tests which were instituted by British Aerospace became more significant in view of the ambiguities surrounding the use of Redux 322.

Preparation for the tests involved cutting suitable skin and honeycomb coupons (set A) from the pocket's left side and also unskinned honeycomb coupons from the core for use in control specimens (set B). New skins were bonded onto the exposed honeycomb of the test specimens 'A' and onto both exposed honeycomb sides of the control specimens 'B' using Redux 322. Tension tests were carried out to schedule BAER 3051 and in each case with coupons 'A' the new skin bond failed first and at a load representing a strength higher than that required by CM37(4 MPa). However, two of the new bonds in the control coupons did fail at lower strengths.

Two of the 'A' coupons were then re-skinned on the failed side using an adhesive known to be stronger than Redux 322 and the tests were re-run to obtain a measure of the actual strength of the original bond. Failures of the aged Redux 322 bonds from VW25 were achieved at 4.854 MPa and 5.128 MPa and thus they exceeded the original strength requirment.

Follow-up Action

Following the rudder failure on G-BOAE a fleet check found one rudder which had suffered some skin to honeycomb disbonding at the trailing edge. Service Bulletin 55-A-007 was re-issued with some modifications to the inspection instructions and a recommendation on improved sealing of the rudder top and bottom edges. British Airways are carrying out investigations to identify the adhesive used in other rudders and, in view of the possible effects of paint stripper, will review the need for further maintenance action. British Airways also issued new engineering instructions to require Service Bulletin 55-A-007 to be applied before rudders are released to service after repair or overhaul.

The Civil Aviation Authority has been in communication with the French authorities about this failure and Air France, the only other operator of the type, are in receipt of the revised edition of the Service Bulletin 55-A-007 issued 2 August 1991.

Concorde 102 , G-BOAE
Lower Rudder VW25
(Right side)

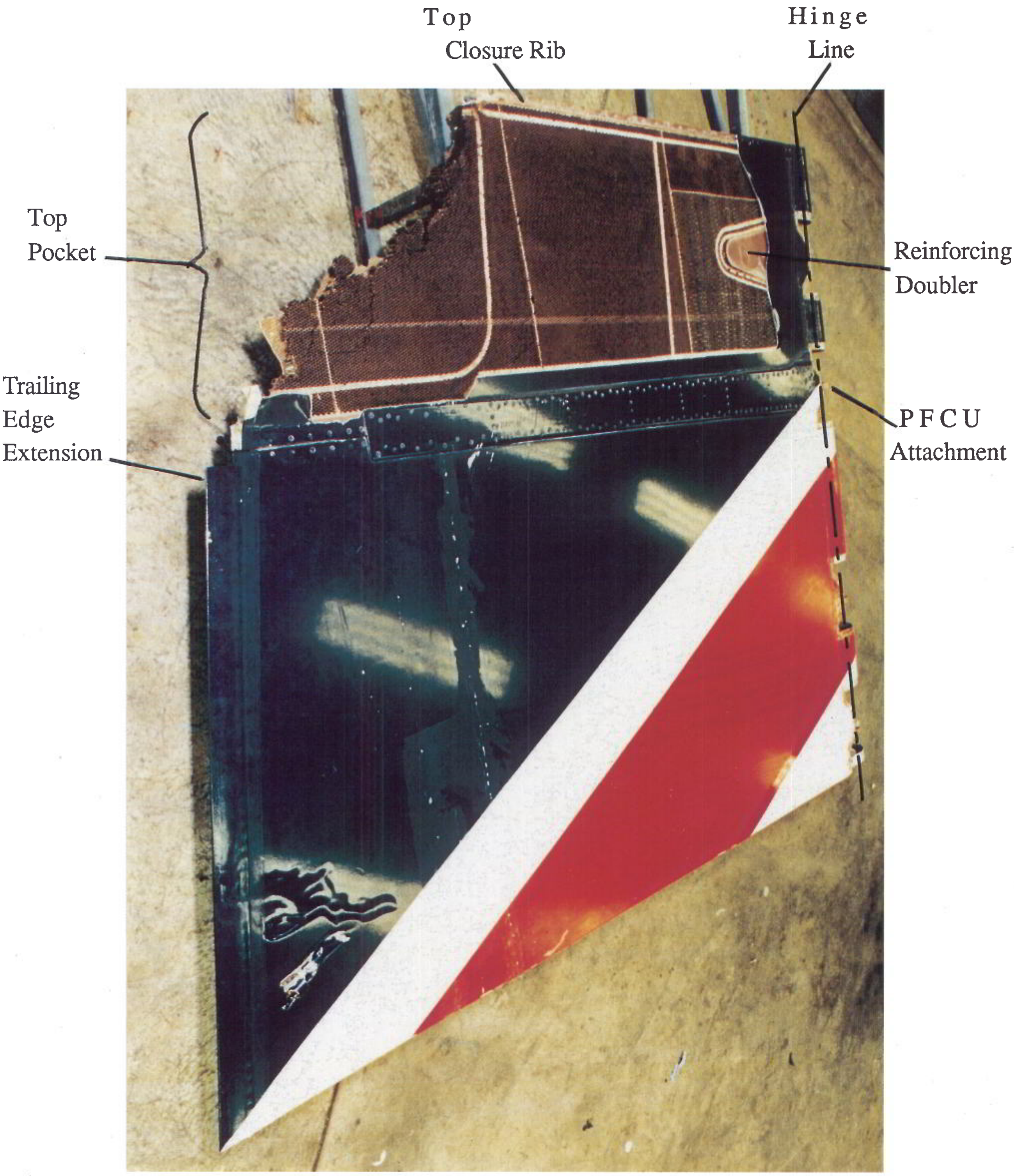

Photo: British Airways